SPECIAL PROJECT FINAL REPORT

Project Title:	Diagnosing subseasonal to seasonal predictability of the East African long rains
Computer Project Account:	spgbmacl
Start Year - End Year :	2018- 2018.
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Summary of project objectives

As part of the NERC/DFID funded project ForPAc: Forecast-based Preparedness Action, we are investigating predictability over East Africa. Establishing the skill and reliability of probabilistic forecasts at subseasonal and seasonal timescales will feed into the ultimate aim of the project, which is to build and improve early warning systems for hydrometeorological hazards over Kenya.

The objective of this special project is to use climate model experiments explore and understand the predictability characteristics of the two East African rainfall seasons as well as forecast performance on subseasonal to seasonal timescales.

Summary of problems encountered

The initial plan was to perform seasonal hindcast experiments with a setup similar to the new operational system SEAS5. It transpired that the computational cost of this setup was prohibitive and a reduced-resolution research version was unavailable at the time of the SP. Instead experiments have all been carried out with a slightly older version of the model: CY41R1, at T255 resolution. This is computationally much reasonable given the SBU allocation of the project and allowed for a significant amount of experiments to be run. This allowed investigation of new hypothesis related to both the long rains and the short rains.

Experience with the Special Project framework

The application procedure was simple and progress reporting requirements are quite reasonable.

Summary of results

Experiments were run in order to investigate four topics:

1. What are the remote drivers of long rains (March-April-May) rainfall variability over East Africa and how are they represented in seasonal forecasts?
2. What were the reasons for the unexpectedly moderate rainfall during the East African short rains (October-November-December) during the strong El Nino event of 2015?
3. January SST in the South Pacific is correlated with March rainfall over East Africa in observations– is this link reproduced in model simulations and what is the mechanism behind the teleconnection?
4. Are different ENSO ‘flavours’ linked to different impacts on the East African short rains?

The analysis of experiments carried out for questions 1 and 2 has been written up into two papers. Paper 1 has been accepted at Climate Dynamics, whilst paper 2 is under final revisions at Journal of Climate. The abstracts and citations are given below.

Paper 1 confirms the Northwest Indian Ocean region as a key driver of interannual variability. This supports previous work (Vellinga and Milton 2018), although an exploration of the mechanism shows potential inconsistencies with current understanding of the pathway.

Paper 2 shows that the expected strong El Nino rainfall did not materialise in OND 2015 over East Africa, due to a moderate Indian Ocean Dipole (IOD) compared to previous El Nino events. However, SEAS5 seasonal reforecasts indicated a significantly strong wet event and strong a zonal SST gradient, with an SST pattern in the East Indian Ocean shared by all ensemble members which was inconsistent with observations. Experiments with relaxation applied to the East Indian Ocean confirm errors in this region as the source of the wet signal in the seasonal forecast. This work suggests the operational ECMWF seasonal forecast may be overestimating the link between strong El Nino positive IOD events.

Analysis of experiments carried out for question 3 is still in progress. Some initial results are available, and these are presented below along with a description of the experiments. Analysis of experiments for question 4 will be carried out soon; details of the experimental runs are provided below.

1 What are the remote drivers of long rains (March-April-May) rainfall variability over East Africa and how are they represented in seasonal forecasts?

Published as:

MacLeod, D. Seasonal forecasts of the East African long rains: insight from atmospheric relaxation experiments, Clim Dyn (2019). https://doi.org/10.1007/s00382-019-04800-6

Abstract:

The impacts of recent droughts and floods over East Africa may have been avoided with accurate and timely early warnings. However skilful predictions for the long rains season from dynamical seasonal forecasts have long proved elusive and understanding of the drivers of interannual variability of this season is incomplete. Although recent work has highlighted several candidates for key drivers of variability during March–April, the representation of East African precipitation and links to remote processes in seasonal climate models is relatively unknown. This is investigated here through use of the atmospheric relaxation technique in coupled seasonal climate hindcast experiments, which also provide an estimate of the upper bound of seasonal predictability from remote sources. Results highlight the key role of the lower troposphere in the northwest Indian Ocean in controlling interannual variability, particularly in March and April. This is in support of recent work suggesting ascent-induced boundary-layer heating this region as a key driver of interannual variability. Results from single-variable relaxation experiments also reveal the importance of correct simulation of humidity for the proper representation of this link. Processes in the southwest Indian Ocean provide a control on May precipitation over southwest Kenya and northern Tanzania, highlighting the role of Somali jet variability in long rains cessation. Relaxation in more remote regions over the Pacific is unable to improve the representation of interannual variability over East Africa in general, although variability in the east Pacific appears to provide a weak control on March rainfall, consistent with previous hypotheses linking decaying ENSO events to early season rainfall. Finally, modelled precipitation anomalies are found to be insufficiently constrained to the coast of Africa. Relaxation (particularly in the northwest Indian Ocean) can improve these spatial biases, however the variance explained by these modes is systematically underestimated in the model and appears insensitive to remote processes. Inadequate representation of local processes over East Africa is proposed as the cause of this underestimation and several candidates are outlined.

2 What were the reasons for the unexpectedly moderate rainfall during the East African short rains (October-November-December) during the strong El Nino event of 2015?

In final revisions as:

MacLeod, D.. Caminade, C The moderate impact of the 2015 El Nino over East AFrica and its representation in seasonal forecasts, Under final revissions at J. Clim.

Abstract:

The El Niño Southern Oscillation (ENSO) has large socio-economic impacts worldwide. The positive phase of ENSO, El Niño, has been linked to intense rainfall over Eastern Africa during the short rains season (October-December). However we show here that during the extremely strong 2015 El Niño the precipitation anomaly over most of East Africa during the short rains season was less intense than experienced during previous El Niños, linked to less intense easterlies over the Indian Ocean. This moderate impact was not indicated by reforecasts from the ECMWF operational seasonal forecasting system, which instead forecast large probabilities of an extreme wet signal, with stronger easterly anomalies over the surface of the Indian Ocean and a colder eastern Indian Ocean/western Pacific than was observed. To confirm the relationship of the eastern Indian Ocean to East African rainfall in the forecast for 2015, atmospheric relaxation experiments are carried out which constrain the east Indian Ocean lower troposphere to reanalysis. By doing so the strong wet forecast signal is reduced. These results raise the possibility that link between ENSO and Indian Ocean Dipole events is too strong in the ECMWF dynamical seasonal forecast system and that model predictions for the East African short rains rainfall during strong El Niño events may have a bias toward high probabilities of wet conditions

3 January SST in the South Pacific is correlated with March rainfall over East Africa in observations– is this link reproduced in model simulations and what is the mechanism behind the teleconnection?

Analysis of climate observations carried out by collaborators on the ForPAc project has identified a reasonably strong correlation (around 0.5) between January sea surface temperatures (SST) in the South Pacific and early long rains rainfall over East Africa in March. In particular the link seems to be that cold SST anomalies in January lead to a particularly wet March.

This link may lead to improvements in forecasting early season rainfall, for the East African season where seasonal predictability is notoriously bad (Kilavi et al 2019, MacLeod 2019). However it is unclear if this link is real and statistically robust.

In order to confirm or reject this link as a potential predictor of March rainfall, climate model experiments were carried out. These were atmosphere-only runs of the IFS in seasonal forecasting mode, where modified SST fields were used to force the atmosphere.

Experiments were carried out based on a control run: a 38 member seasonal forecast ensemble forced by a daily HadISST climatology across a range of initial conditions. Simulations were carried out for five months covering January to May in order to capture the entire long rains season.

The daily HadISST climatology was modified in experiments to include a cold anomaly in the South Pacific, ranging from 1 to 5 degrees.

Two types of forcing modification were used in different experiments:

- Constant Forcing: the SST anomaly is applied equally for every timestep of the integration
- Time-varying Forcing: the SST anomaly is applied fully in January, reducing linearly to zero between 1-15 of February (to avoid shocks)

The first region in which the SST forcing is modified is defined as Equator-25S, 210-290E. To avoid unphysical SST gradients, a sigmoid smoothing is applied so that the anomaly reduces to zero at 15 degrees of latitude outside the box. Additional regions were been tested to compare the impact of the southerly (15-25S) or equatorial (5S-5N) part of the region.

Results show that when a cold anomaly is applied to the eastern South Pacific region during January, a wet signal is observed over East Africa during March, see figure 1. In particular the signal appears to come from the southern part of the region rather than the equatorial part. These experiments provide evidence that there is a causal link between the regions and that the correlation seen in of observational fields is not spurious. Additional experiments have carried out and work is in progress to build understanding of the pathways of this mechanism. This work will be written up in a paper (the reader is advised to check here, where the citation will appear when the paper is published).

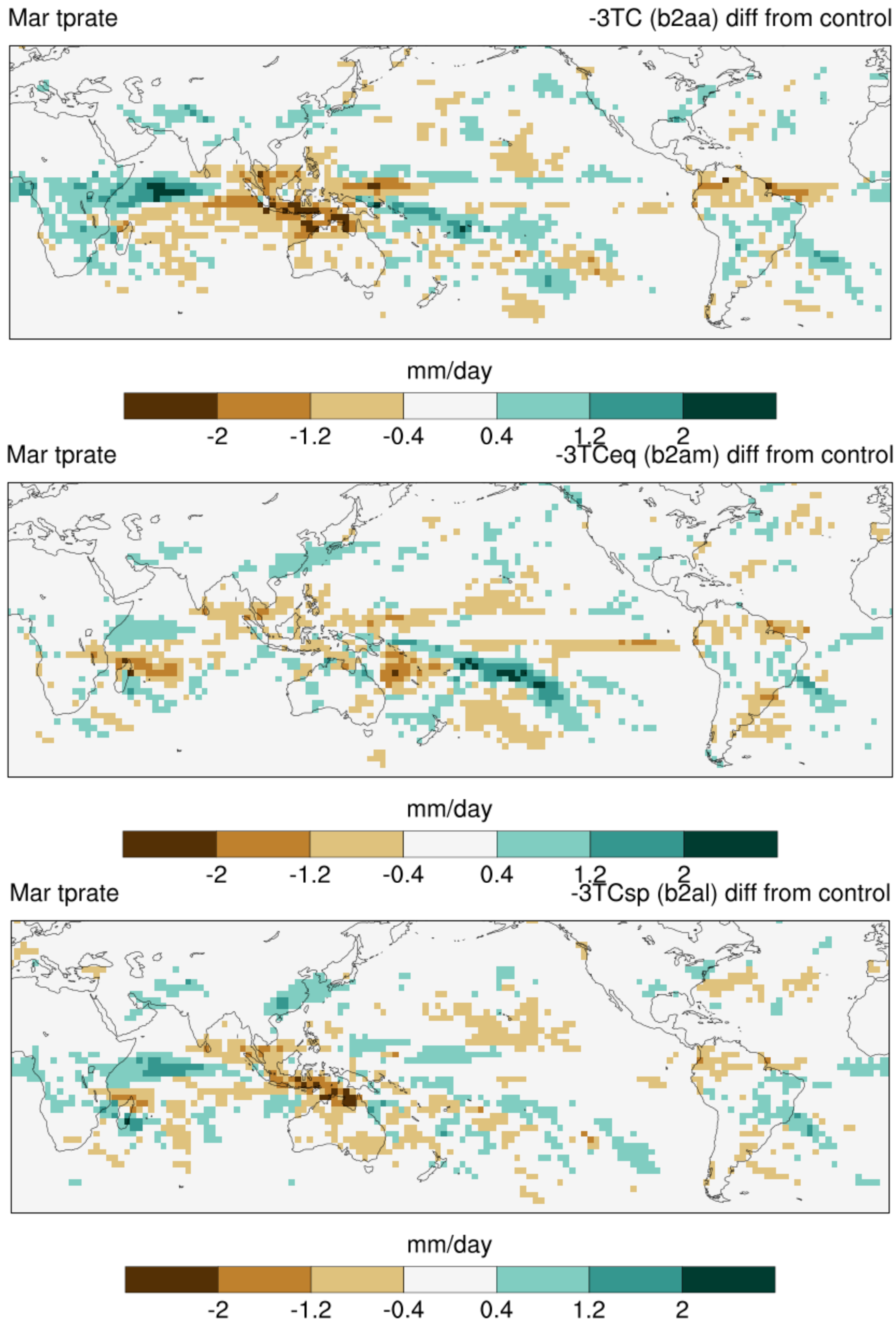

Figure 1 Results from atmosphere-only simulations to investigate a link between the January South Pacific SSTs and East Africa rainfall in March. Anomalous March precipitation (relative to a control) is plotted in each panel, from experiments where a 3K anomaly is subtracted during January in three different regions. The longitude domain for all three is 210-290E: the latitude range is 0-25S (top), 5S-5N (middle) and 15-25S (bottom). All experiments show a significant wet signal in March following cold SST in January, and the comparison between the regions suggests the signal is arising from the southern hemisphere rather than the tropics.

4 Are different ENSO 'flavours' linked to different impacts on the East African short rains?

ENSO has long been known to impact the short rains (October-November-December) over East Africa, with El Nino events strongly associated with increased rainfall and La Nina events with lower rainfall than normal (Nicholson 2017). However the recent experience of ForPAc partners at the IGAD Climate Prediction and Applications (ICPAC) and Kenya Meterological Department (KMD) has been that recent events have not had the expected impacts. It has been suggested that this may be related to the different spatial pattern of SST anomalies during some ENSO events. In particular it is hypothesised that the El Nino impact on short rains rainfall is different during when the warming is more central (i.e. during an El Nino 'Modoki' event as observed in 2018). Given that the frequency of Central Pacific El Nino events appears to be increasing (Freund et al 2019), it is important to build understand of how the spatial pattern of Pacific warming influences the teleconnection to East Africa.

To that end atmospheric-only experiments have been carried out. These are four month initialized forecasts from 1-September, covering the short rains period. In each experiment an SST anomaly is introduced to the climatological daily SST forcing. Anomalies of +1, +2, -1 and –2K are applied in each of the regions corresponding to the standard Nino 3, Nino 3.4 and Nino 4 regions (figure 2). Analysis (to be completed) will focus on the remote impact of these heating anomalies on East Africa precipitation as well as the modulation of tropical circulation induced by heating in different regions. Additional experiments were also carried out in which a negative SST anomaly was added to the Gulf of Aden, following an observation of anomalous SST during the unexpectedly dry 2018 season.

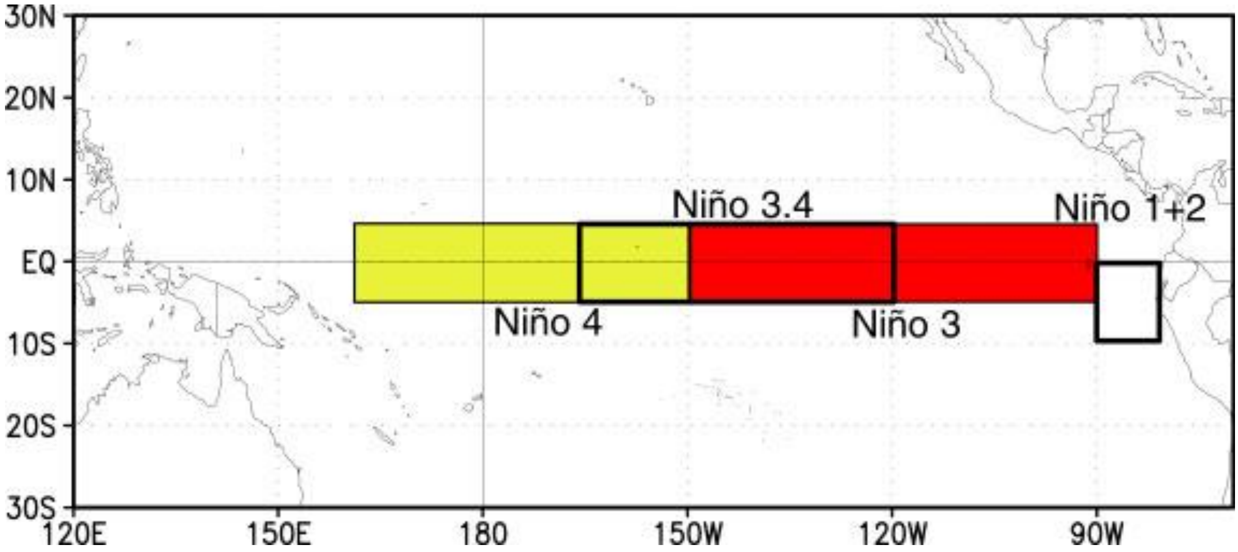

Figure 2 The standard ENSO regions (figure from NOAA). Forced-SST experiments have been carried out in which a warm or cold anomaly is applied in each of the regions Nino 3, 3.4 or 4, to explore the link between the longitudinal position of ENSO events and East African rainfall.

List of publications/reports from the project with complete references

MacLeod, D. Seasonal forecasts of the East African long rains: insight from atmospheric relaxation experiments, Clim Dyn (2019). https://doi.org/10.1007/s00382-019-04800-6

MacLeod, D.. Caminade, C The moderate impact of the 2015 El Nino over East AFrica and its representation in seasonal forecasts, Under final revissions at J. Clim.

Other papers referenced in this report

Freund, M.B. et al. 2019. Higher frequency of Central Pacific El Niño events in recent decades relative to past centuries. Nature Geoscience, 12(6), p.450.

Kilavi M, et al. Extreme rainfall and flooding over central Kenya including Nairobi city during the "long rains" season. 2018: Causes, predictability and potential for early warning and actions. *Atmosphere* 9(12), 472

MacLeod DA. 2019. ECMWF Report: An atlas of seasonal forecast verification over the Greater Horn of Africa, comparing System 4 and SEAS5. Part 1: Precipitation www.ecmwf.int/node/18906.

Vellinga, M. and Milton, S.F., 2018. Drivers of interannual variability of the East African "Long Rains". Quarterly Journal of the Royal Meteorological Society, 144(712), pp.861-876.

Other related papers

It may be worth drawing the attention of any readers interested in this topic to two technical reports which have been published at ECMWF (not peer reviewed). These reports document the performance over System 4 and SEAS5 over the region. Links to these can be found below.

MacLeod DA. 2019. ECMWF Report: An atlas of seasonal forecast verification over the Greater Horn of Africa, comparing System 4 and SEAS5. Part 1: Precipitation www.ecmwf.int/node/18906.

MacLeod DA. 2019. ECMWF Report: An atlas of seasonal forecast verification over the Greater Horn of Africa, comparing System 4 and SEAS5. Part 1: 2m temperature https://www.ecmwf.int/node/18923.

Future plans

The continuation of this activity will involve analysis of the experiments described in section 3 and 4, with the ultimate aim as publishing in two separate papers. There are no active or new special projects related to this work.